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FINAL REPORT

"Study of the Fluctuations in the Cosmic X-Ray Background"

SAS-3 Guest Investigator Program

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FINAL TECHNICAL REPORT

A. Introduction

The performance of the research covered by this grant has led us into several distinct, but ultimately related, programs. Each of these is discussed separately below. The final section of the technical part of this report is an attempt to synthesize the results of the various programs.

At the outset it is probably useful to restate the two major questions which we would ultimately wish to answer through investigations of this sort; they are 1) what is the origin of the cosmic X-ray background (hereinafter CXB), and 2) what is the origin of the fluctuations in the CXB? Note that the answers to these two questions might or might not be the same (i.e., the class of sources which make a dominant contribution to the total flux might but do not have to do the same for the fluctuations). Also they may be photon energy dependent and, in the case of the fluctuations, angular scale dependent.

B. Comparison of SAS-3 and Other CXB Measurements

In addition to early rocket flights, the CXB has been studied using four major satellite experiments: Uhuru, Ariel-5, SAS-3, and HEAO-1 in chronological order. Our analysis of the SAS-3 inclined tube collimator data was carried out in collaboration with Drs. H. Schnopper and J. Delvaille of the Center for Astrophysics. Dr. D. Schwartz of the same institution made the Uhuru data available to us while Drs. A. Fabian of Cambridge University and E. Boldt of the Goddard Space Flight Center did the same for

the Ariel-5 and HEAO-1 data, respectively. Each data set gives a map of CXB at energies ≥ 2 KeV covering a substantial fraction of the sky with a resolution of order degrees.

All such measurements of the CXB are difficult because they involve maintaining absolute flux calibration and completely consistent data reduction procedures over extended periods of time and regions of the sky; moreover, with the exception of the HEAO-1 experiment, all of the observations were carried out with instruments designed for use on discrete sources. Thus, it was deemed necessary to determine the reliability of the various data sets by intercomparisons. A series of cross-correlations led to the following conclusions:

- 1) All data sets agreed on the mean brightness of the CXB, 3×10^{-8} erg/s/cm²/ster in the 2-7 KeV band.
- 2) All data sets agree that the North Galactic Pole (NGP) region is somewhat (~ 2%) brighter than the South Galactic Pole (SGP) region.
- 3) All data sets agree that typical fluctuation amplitudes are of order of a few percent.
- 4) On scale from degrees to several tens of degrees the Uhuru and HEAO-1 data sets showed by far the strongest correlation and are, therefore, presumably the most reliable indicators of structure on these scales.
- 5) On the same scales, Ariel-5 data gave the worst cross-correlations and was thus not used further.
- 6) The SAS-3 data which covered the smallest region of the sky, essentially only the NGP and SGP caps, appeared to give (along with the small HEAO-1 ecliptic pole fields) the best data for studying small angular scale fluctuations and their covariance.

Having evaluated the various CXB data sets in this way, we always chose in further studies to use the data set we regarded as most reliable for the particular energy and angular scale in question.

C. Intensive Photographic Survey of Extreme CXB Fluctuation Fields

A primary goal of this research program was to obtain high quality optical survey data of fields with unusually bright or faint CXB emission for the purpose of searching for a population of optical objects whose presence correlates with the CXB brightness. This observational program has been successfully carried out. A total of 6 nights on the Mt. Palomar 48-inch Schmidt camera and 3 nights on the KPNO 36-inch Schmidt camera with objective prism were secured and used to obtain U, BV, and R broad band direct plates plus $\sim 10^3$ A/mm slitless spectral plates of 4 fields. Each field was chosen on the basis of either SAS-3 (4 NGP fields) or HEAO-1 (4 SGP fields) to have unusually high or low CXB brightness or to have unusually high resolution CXB data available.

These plates are currently being digitized using the Princeton PDS plate scanner. The digitized images are stored on magnetic tape and analyzed using the PDP-11/60 based Peyton Hall Image Processing System (PHIPS) to catalog positions, magnitudes, colors, shape parameters, and rough spectroscopic classifications of the $\sim 10^5$ images per field. The nonparametric approach used by the PHIPS software is described in the attached reprint. Preliminary investigations indicate that the plate material is of good quality, and that sharp differentiation of the various classes of optical sources is possible.

D. Correlation of Large Scale CXB Fluctuations with Galaxy Catalogs

A second primary goal of this project was to extend our study (Turner, E.L., and Geller, M.J. 1980, Ap.J., 236, 1.) of correlations of large angular scale fluctuations in the CXB with the optical flux from nearby galaxies. In particular, improvements in the resolution and reliability of the CXB data and experimentation with various strong source removal strategies were planned. This program has also been accomplished.

Two basic versions of the optical catalogs, counts and total flux in the blue, were each cross-correlated with each of two versions of the CXB data, one with individually detected strong X-ray sources ($\geq 3\sigma$) deleted and one with no such editing. The purpose of the version with strong source rejection was to remove correlations due solely to known classes of X-ray sources. The optical data were taken from the Second Reference Catalog of Bright Galaxies and are complete to a limit of $m_B = 13.2$. Each of the four cross-correlations were carried out separately in the NGP and SGP regions for $|b| \geq 40^\circ$. The angular resolution of the maps was 3° . The resulting linear correlation coefficients and the size in number of sky bins of each comparison are given in Table I.

These results show that nearly all of the contribution of local galaxies to the CXB fluctuations are from known classes of individually observable X-ray sources, but there is some weak evidence for a small additional contribution from some unknown class of sources.

TABLE I

CXB - GALAXY CATALOG CROSS-CORRELATIONS

<u>CXB data type</u>	<u>Number of bins</u>	<u>Correlation Coefficient</u>	
		<u>Optical Total Flux</u>	<u>Galaxy Counts</u>
NGP No sources	283	0.02	0.31
NGP Sources in	314	0.20	0.70
SGP No sources	142	0.03	0.17
SGP Sources in	188	0.74	0.02

E. Small Angular Scale Covariance of the CXB

The strong clustering of galaxies on small angular scales could leave its signature in the CXB if its sources were distributed like the galaxies. In collaboration with Dr. J. Devaille we have attempted to measure this effect in the time covariance of the SAS-3 inclined tube collimators which continuously swept out great circle observations during RMC operations. In order to recover the real CXB covariance it is necessary to remove the effects of both the tube collimator beam shape and time correlated noise from the signal. Computer models of these processes have been developed, but at present it is only possible to say that the SAS-3 CXB data is consistent with the galaxy covariance function.

F. Theory of Galactic Halo Gas Contribution

Discovery of a hot component of the interstellar medium (ISM) have greatly strengthened speculations that the Galaxy might possess a supernovae heated, radiatively cooled plasma halo. If so, it will emit strongly in the soft X-rays and may well be extremely patchy and uneven in distribution. It is easy to show from a knowledge of the ISM pressure and the Galactic supernova rate that such emission could not account for much of the CXB flux; however, it could give rise to the CXB fluctuations at low energies. Some details of this scenario have been investigated theoretically; it was suggested to us by Dr. J.P. Ostriker.

G. Synthesis and Conclusions

Clearly we are not yet in a position to give unambiguous answers to the fundamental questions of the CXB origin discussed in section A. Nevertheless, it is clear that substantial progress has occurred. The emerging picture indicates that neither the total CXB flux nor the fluctuations are completely dominated by any single class of sources. Quasars clearly contribute a substantial fraction (say 30 to 60%) of the total flux while galaxy cluster X-ray sources and galactic nuclear activity also make non-negligible contributions. It appears from the large angular scale CXB-galaxy correlations that no class of relatively low luminosity (i.e., individually undetected) X-ray sources associated with galaxies can play a major role in supplying the total flux. The origin of the CXB fluctuations look even more complex. It is hard to avoid the conclusion that the NGP-SCP difference and some other features of the CXB map are associated with the local anisotropy in the galaxy distribution (i.e., the Local Supercluster). It also appears reasonable to suppose that at least some large angular scale structures in the CXB are due to emission from hot galactic halo gas. On small angular scales, the hypothesis that distant sources contribute significant fluctuations remains open and apparently testable.

The relatively complicated scenario outlined above along with the somewhat unsatisfactory quality of data on the CXB go far toward explaining why it, among the various forms of cosmic background radiation, has yielded its origin and nature so slowly and grudgingly.